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ABSTRACT

This study applies multidimensional scaling (MDS) to a knowledge organization problem involving 12 concepts in pulmonary physiology. The concept structures were derived from individual medical and veterinary students before and after focused instruction. One hundred seventy medical students and 85 veterinary medical students completed a questionnaire about the similarity or relatedness of the concepts in pairs before and after instruction. Results from the study permit two general conclusions. The first is that the data pass the coherence test in that the pairwise similarity judgment data about the concepts met the scientific standards for goodness of fit. The concept organization data analyzed by MDS and concept educational achievement data contained in the final examination scores were trustworthy. However, the other conclusion is that the correspondence of the data is not established. Data suggest that knowledge assessment using structural methods like MDS produces results that are different from results obtained by knowledge assessment using multiple-choice tests. Each of these two approaches to student assessment in pulmonary physiology yields solid data, but for practical purposes, the data have no common variance. (Contains 2 tables and 24 references.) (SLD)

Multidimensional Scaling Assessment of Medical and Veterinary Student

Knowledge Organization of Pulmonary Physiology Concepts

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Multidimensional Scaling Assessment of Medical and Veterinary Student Knowledge Organization of Pulmonary Physiology Concepts

Research in a variety of fields including physiology (1-3), medicine (4), research methods and statistics (5), computer programming (6), psychology (7), biology (8), and teacher education (9) has tried to capture or represent the cognitive structure, the intellectual organization, of concepts acquired by learners at different educational levels. This research is based on two fundamental assumptions. First, the ability to organize, simplify, and store a large body of educational material in a specific field is essential for the development of expertise (10). The coherence of information increases as individuals learn to organize and simplify data and concepts for storage in memory. Meaningful learning involves the ability to structure educational material, not just the ability to acquire material in volume. Second, the organization of concepts in memory mediates their recall and use. As the conceptual organization of educational material is simplified its retrieval from memory becomes automatic and the cognitive workload needed for recall is reduced. Thus as pointed out by Nobel Laureate H.A. Simon in his landmark book, *Models of Thought* (11), the ways in which experts and learners in a field of study intellectually organize its key concepts affects their ability to retrieve and use the material.

Studies in medical education have been at the leading edge of research on knowledge organization. This work has been done using several different research methods including qualitative concept mapping (1, 12-14), use of "thinking aloud" protocols in the cognitive science tradition (15, 16), multidimensional scaling (MDS) (4),

assessment of semantic structures (17, 18), and concept network analysis using the Pathfinder scaling algorithm (2, 3). While the individual studies within this body of research vary in scope, measurement methods, data analysis procedures, and scientific rigor they all address the research goal of organizing medical information with coherence and parsimony.

Quantitative analysis of concept organization via MDS or Pathfinder network scaling holds particular promise for medical education research. In contrast with qualitative approaches to research on concept formation and organization, these quantitative methods are rigorous, can be replicated, and allow for statistical analyses of concept data sets. For example, such analyses permit investigators to systematically study issues including expert-novice differences in concept organization (6, 7), changes in concept structure due to educational interventions (5), correlations between indexes of concept organization and independent measures of educational achievement (3, 5, 7), and variation among experts in concept organization (2).

MDS is one means to display the judged similarity or difference of a set of stimuli (e.g., pulmonary physiology concepts) on a spatial map (19). Pairs of stimuli (concepts) are judged in terms of their similarity or difference. Following quantitative analysis, stimuli that are consistently judged to be similar are graphically displayed in geometric space to be closer than stimuli that are consistently judged to be different.

There is controversy about the propriety of MDS to map judgments about nonphysical entities like concepts in the medical basic sciences. Some investigators question the geometric assumptions that underlie such analyses and express concern about the interpretability of results when the entities being studied are intangible (20).

By contrast, other researchers have shown in theory (21) and in practice that MDS is a useful method to analyze judgments about such abstract entities as physics principles (22) and concepts in developmental psychology (23).

This study applies MDS to a knowledge organization problem involving 12 concepts in pulmonary physiology. The concepts are chemoreceptors, lung gas exchange, ventilation, spinal cord, perfusion, intrapleural pressure, respiratory mechanics, surface tension, resistance, control of breathing, diffusion, and partial pressure. Concept structures were derived in several dimensions from individual medical and veterinary students before and after a period of focused instruction. The study addresses three questions. First, does the research task we devised about pulmonary physiology concept formation and representation yield data that are suitable for MDS analysis? Second, can an MDS solution account for a meaningful proportion of variance in medical and veterinary students' concept representations? Third, do individual differences in the way in which medical and veterinary students intellectually organize the pulmonary physiology concepts, captured by MDS, correlate with course examination achievement?

Methods

Participants. One hundred seventy Northwestern University medical students and 85 University of Wisconsin veterinary medical students volunteered to participate in the study during the Fall of 1996. They supplied preinstruction and, with some attrition, postinstruction data. This occurred in the context of a first year physiology course section or a complete course at each institution, respectively.

Measurements. A questionnaire was constructed that presented all possible

$n(n-1)/2 = 66$ pairs of the 12 concepts randomized for presentation order (left-right) and sequence (1-66). Instructions directed research participants to provide a judgment about the degree of similarity between or relatedness of the two concepts in each pair on a scale of 0 (completely unrelated) to 9 (highly related). This judgment task was completed on both occasions by most of the medical and veterinary medical students in approximately 20 minutes.

Data Collection. Northwestern University medical students and University of Wisconsin veterinary medical students completed the questionnaire in class, immediately before and after in instructional unit on pulmonary physiology that lasted three weeks.

Data Analysis. Data analyses were performed using the individual differences (INDSCAL) option of the ALSCAL algorithm in SPSS. For each institution (Northwestern, Wisconsin) and for each occasion (preinstruction, postinstruction) the MDS analysis yielded solutions in dimensions ranging from two through six. For each dimensional solution, coefficients of S-Stress and Stress were calculated as indexes of "goodness of fit" of the data to the statistical algorithm. In addition, an index of variance explained or accounted for (R^2) was calculated for each dimensional solution. This is a measure of internal consistency for each group of students on each occasion. An increase in MDS R^2 from preinstruction to postinstruction about a set of concepts for a student group indicates the concepts are becoming increasingly coherent, conceptually meaningful, for the students. Finally, individual students' subject weights for the MDS dimensions contained in the most interpretable solution were correlated with their scores on a course examination covering the pulmonary physiology material.

Results

A summary of the data analysis is given in Table 1. MDS solutions ranging from two to six dimensions are shown for the Northwestern University medical students pre and post instruction data and for the University of Wisconsin veterinary medical students pre and postinstruction data.

Table 1 here

Attrition from the study occurred for the volunteer students in both groups. For the Northwestern medical students the pretest to posttest loss was from 170 to 131 students, a drop of 23%. For the University of Wisconsin veterinary medical students the pretest to posttest loss was from 85 to 73, a 14% reduction. Students lost to followup were not present or refused to participate on the occasion of the posttest, or refused to participate when contacted subsequently.

In response to the first study question, the research task clearly produced data suitable for MDS analysis. Of the various dimensional solutions displayed for the two institutions (Northwestern, Wisconsin) and the two occasions (pre and postinstruction), the four dimensional solution produced the most interpretable results. The rule-of-thumb in INDSCAL research is that a dimensional solution should have a Stress level at or below .15 to provide a good fit of the data to the computing algorithm (19). In addition, in studies like this investigation it is important to demonstrate a substantial increase in variance accounted for (R^2) from pretest through educational intervention to posttest as an index of increased conceptual coherence among the medical and veterinary medical students.

The four-dimensional MDS results displayed in Table 1 clearly achieved the minimum expectations for "goodness of fit" (Stress) and variance accounted for (R^2). For the Northwestern data the Stress levels at pre and posttest are .162 and .150, respectively. The R^2 from pretest to posttest increases from .552 to .645, a 17% boost. For the University of Wisconsin data the Stress levels at pre and posttest are .169 and .148, respectively. The R^2 from pretest to posttest jumps from .500 to .673, an increase of 35%. Thus on grounds of "goodness of fit" (reduced Stress) and improvement in conceptual coherence (increased R^2) the four-dimensional MDS solution provides a parsimonious organization of the pulmonary concept judgment data.

Table 2 presents correlations of individual students' subject weights for each of the four dimensions (pre and postinstruction) with their scores on course examinations created independently at Northwestern University and the University of Wisconsin. The reliability coefficient (KR-20) for the Northwestern examination was .79. For the University of Wisconsin examination the reliability coefficient was .86.

Table 2 here

Outcomes from this analysis show that, with one exception, there is no correlation between students' structural knowledge organization of the 12 pulmonary physiology concepts represented by MDS and their achievement on course examinations covering the same material. The sole exception is a statistically significant negative correlation between students' scores on the third MDS dimension and final examination scores for the University of Wisconsin veterinary medicine pretest data. From an array of 16 correlation coefficients, a single significant outcome may also be an artifact of chance.

Discussion

Results from this study permit two general conclusions. The first conclusion concerns what psychologist Kenneth Hammond (24) would call the *coherence* or internal consistency of our data. The second conclusion addresses Hammond's notion about the *correspondence* of data, their link with different measures of a presumably similar construct.

Our data clearly pass the *coherence* test. The pairwise similarity judgment data about the pulmonary physiology concepts, arrayed in four dimensions by the INDSCAL MDS algorithm, meet scientific standards for "goodness of fit" (Stress) and variance accounted for (R^2). Students' final examination scores at both Northwestern and Wisconsin also reach acceptable levels of test reliability. Thus customary psychometric indexes of coherence and internal consistency show that the (a) concept organization data analyzed by MDS and (b) concept educational achievement data contained in final examination scores are trustworthy.

However, the *correspondence* of our data is not established. The data suggest that knowledge assessment using structural methods like MDS produces results that are different from results obtained by knowledge assessment using multiple-choice tests. In this study, each approach to student assessment in pulmonary physiology yields very solid data, but for practical purposes the data have no common variance.

This study outcome is in sharp contrast with past research where correlations have been demonstrated between measures of student structural knowledge and customary measures of school achievement (3, 5, 7, 9). However, the studies just cited used the Pathfinder scaling algorithm to assess knowledge organization rather than MDS. This

suggests that the approach used to assess knowledge organization among concepts (or other entities) may govern an investigator's ability to link student structural knowledge with acquired fund of knowledge.

Future work by our research group will continue to assess medical and veterinary student knowledge organization in both basic science and clinical domains. An essential feature of this work will be a search for ways to establish the *correspondence* of measures of structural knowledge with other measures of knowledge acquisition and use.

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Table 1

Pulmonary Physiology Concepts: A Multidimensional Scaling Analysis of Proximity Data

	nDim	S-stress	Stress	R-squared	Dimension Importance
NU Preinstruction					
	2	.382	.287	.515	.335, .180
(n=170)	3	.320	.218	.509	.193, .182, .133
	4	.265	.162	.552	.213, .128, .106, .105
	5	.226	.127	.557	.177, .125, .098, .082, .077
	6	.194	.107	.549	.193, .084, .078, .067, .064, .064
NU Postinstruction					
	2	.341	.259	.600	.339, .261
(n=131)	3	.283	.191	.624	.222, .222, .179
	4	.234	.150	.645	.219, .199, .144, .112
	5	.194	.133	.651	.181, .172, .113, .102, .083
	6	.164	.113	.664	.172, .172, .087, .086, .080, .068
Madison Preinstruction					
	2	.402	.291	.468	.277, .191
	3	.326	.203	.494	.209, .157, .129
(n=85)	4	.270	.169	.500	.152, .148, .103, .098
	5	.231	.136	.507	.127, .118, .099, .083, .080
	6	.196	.115	.518	.109, .109, .079, .075, .074, .073
Madison Postinstruction					
	2	.340	.243	.627	.395, .232
(n=73)	3	.283	.183	.657	.256, .224, .177
	4	.237	.148	.673	.268, .146, .137, .122
	5	.195	.129	.675	.222, .136, .125, .100, .092
	6	.162	.109	.697	.172, .138, .107, .106, .103, .071

Table 2

Correlations of Final Examination Scores with Subjects' Pre- and Post-Instruction Dimensional Weights

NUMS Medical Physiology Final Examination	Mean = 72.97	SD = 8.92	Reliability = .79	
	Dim-1	Dim-2	Dim-3	Dim-4
NU Pre	.03	-.06	-.08	-.05
NU Post	-.01	.08	.05	.15
UW Veterinary Physiology Final Examination	Mean = 87.28	SD = 8.81	Reliability = .86	
	Dim-1	Dim-2	Dim-3	Dim-4
UW Pre	.17	.02	-.25*	-.08
UW Post	.09	.14	-.07	.21

* Correlation is significant at the 0.05 level

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